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Large engineering project risk management using a Bayesian belief network

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ABSTRACT

This paper presents a scheme for large engineering project risk management using a Bayesian belief network and applies it to the Korean shipbuilding industry. Twenty-six different risks were deduced from expert interviews and a literature review. A survey analysis was conducted on 252 experts from 11 major Korean shipbuilding companies in April 2007. The overall major risks were design change, design manpower, and raw material supply as internal risks, and exchange rate as external risk in both large-scale and medium-sized shipbuilding companies. Differences of project performance risks between large-scale and medium-sized shipbuilding companies were identified. Exceeding time schedule and specification discontent were more important to large-scale shipbuilding companies, while exceeding budget and exceeding time schedule were more important to medium-sized shipbuilding companies. The change of project performance risks was measured by risk reduction activities of quality management, and strikes at headquarters and subcontractors, in both large-scale and medium-sized shipbuilding companies. The research results should be valuable in enabling industrial participants to manage their large engineering project risks and in extending our understanding of Korean shipbuilding risks.

1. Introduction

Project risk management, one of the main subjects of project management (Raz & Michael, 2001), is the planning, organization, monitoring and control of all aspects of a project and it consists of risk identification, risk qualification, risk response development, and risk response control (Saynisch, 2005). Miller and Lessard (2001) pointed out that understanding and managing project risks in large engineering projects are challenging tasks at the early phase. The failure of large engineering projects has highlighted the importance of risk management mainly in the defense, construction and oil industries due to the serious damages that may be incurred (Williams, 1995). Active research has investigated process modeling and the methodologies of project risk management, in order to develop a systematic approach and integrated methodology of project risk management (del Cano & de la Cruz, 2002; Raz & Michael, 2001).

The use of diagrams such as cause and effect diagram and influence diagram is one of the methodologies for project risk management. A diagram is suitable for the modeling of conditional probability relationships among risks, and is useful when handling complex problem. However, it is not easy to construct relationships and it is more complex than intuition-based analysis, so it has not been applied to project risk management as a widely used methodology (Han & Diekmann, 2001; Lyons & Skitmore, 2004; Raz & Michael, 2001; Simister, 1994).

A Bayesian belief network is a graphical model that presents probabilistic relationships among a set of variables by determining the causal relationships among them (Heckerman, 1997). Because a Bayesian belief network constructs a cause and consequence diagram easily, it could be a suitable methodology for project risk management with systematic and integrated processes. Therefore, this study presents a project risk management procedure using a Bayesian belief network, applies this procedure to the Korean shipbuilding industry, and performs a project risk comparison between large-scale and medium-sized shipbuilding companies.

2. Literature review

2.1. Project risk management

The main purpose of project risk management is to identify, evaluate, and control the risks for project success. The measurement of project success is difficult because it may be changed by project phase, and many stakeholders have different criteria to evaluate project success. However, the project success criteria are generally measured by time overrun, cost overrun, and technical performance (Baccarini & Archer, 2001; Williams, 1993).

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Table 1
Examples of project risk management process

Chapman	Cooper et al.	NASA	Boehm	Patterson and Neailey	Tummala and Leung	Zhi
Various industries	Various industries	Various industries	Software development	Automotive manufacturing	Utility sector	Construction
Define/focus	Establish the context	Risk planning				Risk classification
Identify	Identify the risks	Risk identification and characterization	Risk identification	Risk identification	Risk or hazard identification	Risk identification
Structure/ownership				Risk assessment	System hazard analysis	Risk assessment
Estimate	Analyze the risks	Risk analysis	Risk analysis Risk prioritization	Risk analysis	Ranking of hazards	
Evaluate			Risk management planning		Development of action plans	
Plan	Evaluate the risks	Risk mitigation and tracking	Risk resolution	Risk reduction/ mitigation	Risk evaluation	Risk response
Manage	Treat the risks		Risk monitoring	Risk monitoring/loop	Risk control and monitoring	

Various studies have proposed the process of project risk management for project success, as shown in Table 1 (Boehm, 1991; Chapman, 1997; Cooper, Grey, Raymond, & Walker, 2005; NASA, 1995; Patterson & Neailey, 2002; Tummala & Leung, 1996; Zhi, 1995). Though some studies used a detailed process for specific application (Kwak & Stoddard, 2004), or a modified process for evaluating the risk ranking of various projects (Baccarini & Archer, 2001), the general project risk management process consisted of four phases: risk classification and identification, risk assessment, risk analysis, and risk control.

In each phase of a project risk management process, common methodologies proposed by Lyons and Skitmore (2004), Raz and Michael (2001) and Simister (1994) are as follows:

In the risk identification phase, the main methodologies are brainstorming, document review, Delphi technique, checklist analysis, and assumptions analysis. The risk analysis phase can be divided into qualitative risk analysis and quantitative risk analysis. The former includes risk probability and impact assessment, and probability and impact matrix, while the latter includes sensitivity analysis, expected monetary value analysis, and decision tree analysis using utility theory (de Klert, 2001). Other methodologies include simulation (Duffey & van Dorp, 1999), cause and effect diagram, influence diagram, game theory, and fuzzy theory (Carr & Tah, 2001; Kuchta, 2001). Fault tree and event tree analyses are also used in technical risk analysis as quantitative risk analysis (Molak, 1997; NASA, 1995). Since various methodologies exist in each process of project risk management, del Cano and de la Cruz (2002) recommended suitable methodologies with consideration for project scale, complexity, and organization risk maturity level. They also suggested that most of the methodologies are suitable for large engineering projects.

However, Han and Diekmann (2001) described the following disadvantages of these methodologies: intuition-based analysis and analytical methods are unsuitable for complex problems, a statistical approach requires tremendous effort in data collection, a decision tree has complexity in the form of correlated variables, simulation needs a mathematical model and the probability density function needs to be defined for each variable, a neural network is highly sensitive to data set, and an influence diagram requires detailed representation of the relationships. Han and Diekmann (2001) therefore used the cross impact analysis method for construction project go/no-go application. However, the cross impact analysis method has the disadvantages of demanding the experts' estimation of conditional probabilities or joint probabilities of event pairs, or the marginal probability of events (Weimer-Jehle, 2006).

A Bayesian belief network is used in this study for large engineering project risk management because it can easily present a detailed representation of the relationships and calculate conditional probabilities of risk items which are the disadvantages of the influence diagram and cross impact method.

2.2. A Bayesian belief network

A Bayesian belief network, also called a causal network or belief network, is a powerful tool for knowledge representation and reasoning under conditions of uncertainty (Cheng et al., 2002), and visually presents the probabilistic relationships among a set of variables (Heckerman, 1997). It is frequently applied in real-world problems such as diagnosis, forecasting, automated vision, sensor fusion, and manufacturing control (Heckerman, Mamdani, & Wellman, 1995). It has been extended to other applications including transportation (Ulegine, Onsel, Topcu, Aktas, & Kabak, 2007), ecosystem and environmental management (Uusitalo, 2007), and software risk management (Fan & Yu, 2004). A Bayesian belief network has many advantages such as suitability for small and incomplete data sets, structural learning possibility, combination of different sources of knowledge, explicit treatment of uncertainty and support for decision analysis, and fast responses (Uusitalo, 2007). It is therefore applied to decision support systems with uncertainty.

A Bayesian belief network consists of qualitative and quantitative parts (van der Gaag, 1996). The qualitative part of a Bayesian belief network, so-called structural learning, is the graphical representation of independence holding among variables and has the form of an acyclic directed graph. There are two methods for structural learning using data. One is a Bayesian approach based on scoring and searching, the other is a constraint-based approach based on independence test. A Bayesian approach finds the optimal model structure from data after a Bayesian belief network is constructed by the user's priori knowledge, and a constraint-based approach finds the optimal model structure from conditional dependences in each pair of variables. However, a constraint-based approach is commonly used due to its computational simplicity compared to the Bayesian approach (Uusitalo, 2007).

A PC algorithm which is widely used in the constraint-based approach connects all nodes, deletes connections according to the conditional independence from any node as a center to neighbor nodes, and finally represents the directions (Spirtes, Glymour, & Scheines, 1993). Abellan, Gomez-Olmedo, and Moral (2006) highlighted the advantages of a PC algorithm in having an intuitive basis and the ability to recover a causal structure of an equivalent true model for the data. Therefore, this study used a PC algorithm based on Spirtes et al. (1993).

The quantitative part of a Bayesian belief network, the so-called parameter learning, finds dependence relations as joint conditional probability distributions among variables using cause and consequence relationships from the qualitative part and data of variables. This study used unrestricted multinomial distribution based on Heckerman (1997). If a Bayesian belief network is constructed, sensitivity analysis is capable of analyzing how much a specific node is influenced by other nodes. Sensitivity is represented by entropy: a larger entropy between nodes produces a bigger influence.

Although a Bayesian belief network has many advantages, it also has the disadvantage of requiring that continuous variables be discretized (Uusitalo, 2007). In an analysis including continuous variables, which need to be transformed to discretized variables, the discretizing process could bring about information loss. In order to avoid this disadvantage, this research used only discretized variables.

As mentioned above, if a Bayesian belief network is applied to project risk management, a cause and consequence diagram among the risks can be easily constructed, risk probabilities can be obtained by calculating the joint conditional probability among risks, and major risks which affect project performance can be identified from entropy calculation. Therefore, in the remainder of this research, project risk management is undertaken in the Korean shipbuilding industry using a Bayesian belief network.

3. Project risk management procedure using a Bayesian belief network

As mentioned earlier, a cause and effect diagram or influence diagram is not frequently used in practice, despite graphically expressing the risks because some difficulties are encountered such as complexity in detailed representation of the relationships. However, with a Bayesian belief network it is possible to apply a feedback loop for risk management (even if a Bayesian belief network has no feedback loop itself (Uusitalo, 2007)), construct a cause–consequence relation visually, and provide conditional probabilistic estimations of risks (Fan & Yu, 2004). In this study, therefore, a project risk management procedure using a Bayesian belief network, presented in Fig. 1, was derived from the literature review of Chapter 2 and was applied to Korean shipbuilding project risk management. Through the Bayesian belief network procedure shown in Fig. 1, the risks were identified at a glance, and risk reductions were easily measured by risk control activities.

Step 1. Risk classification and identification

At this stage, the risks which affect the project were categorized, the risk items classified, and the important risks are identified from various sources (e.g. literature review, expert survey, and historical data).

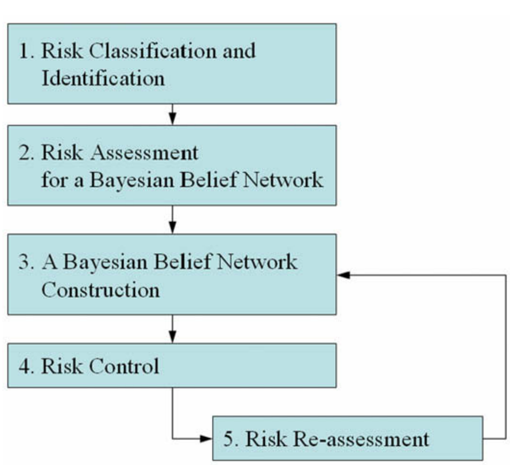

Fig. 1. Project risk management procedure using a Bayesian belief network.

Industries such as land-based construction and shipbuilding have been the subject of research on the risks of large engineering project, but the former has attracted more active research. Although risk classifications have been developed in many different ways in the past, most have focused on the source criteria (Baloi & Price, 2003), although other research has considered other factors for its application. Edwards and Bowen (1998) presented a broad classification of land-based construction project risks using natural (weather systems and geological systems) and human (social, political, economic, financial, legal, health, managerial, technical, and cultural) categories. That classification is used in Ling and Hoi (2006)'s research, and is very similar with the classification of Han and Diekmann (2001) and Zhi (1995) in overseas construction project risk, as well as the classification of Dey, Tabucanon, and Ogunlana (1994) in a pipeline-laying project. Akintoye and MacLeod (1996) included IT development as a risk category, and Mustafa and Al-Bahar (1991) included job site-related and design as risk categories. Gatti, Rigamonti, Saita, and Senati (2007) included operations and revenues for project financing risk management. However, they did not markedly differ from Edwards and Bowen (1998)'s classification.

Of the few studies related to project risk management in the shipbuilding industry, most research has been related to individual risk factors. Lu and Tang (2000) researched about the risk factors of the Chinese shipbuilding industry in the 1980s but they included specifically Chinese environmental risks such as power supply. Moyst and Das (2005) have applied the risk classification of the land-based construction industry to the shipbuilding industry with the aim of determining the factors affecting ship design and construction.

Therefore, this study used the broad risk classification system of the land-based construction industry in which the following detailed risk items were modified or added for adjusting to the shipbuilding industry: refund guarantee (RG), which is an important financial risk in the shipbuilding industry (IBKERI, 2007), risks related to ship design and experienced workers (Brodda, 2004; Moyst & Das, 2005), productivity, which is affected by technology, humans, external stakeholders, and management factors (Phelps, Fleischer, Lamb, & DeGraw, 2003), and other factors which are affected by the value chain (Koenig, 2002).

Alquier and Tignol (2001) divided the risks into internal and external risks, which are respectively those that are supposed to be under company control (e.g. manufacturer's risk of products, processes and resources) and those that the company does not control (e.g. regulation, legal context, currency fluctuations, and environmental protection). In this study, each risk item was divided into internal and external risks.

Step 2. Risk assessment for a Bayesian belief network

At this stage, the risk level of each risk item identified from Step 1 was measured and the dataset was modified for a Bayesian belief network analysis. The risk level was determined by Eq. (1) (Kuo, 1998) using the degree of loss and the probability of occurrence. The dataset was modified using the risk matrix shown in Table 2 to apply a Bayesian belief network

$$\text{Risk} = (\text{the degree of loss}) \times (\text{the probability of occurrence}) \qquad (1)$$

Step 3. A Bayesian belief network construction

A Bayesian belief network was constructed by structural learning and used to examine the relationships among the risk items.

The conditional probability of each risk items was calculated by parameter learning.

Step 4. Risk control

Risk items which affect the project performance were measured by the sensitivity analysis of a Bayesian belief network. Important risk items which should be controlled were selected.

Step 5. Risk re-assessment

After the risk items for the control were decided in Step 4, the extent to which the probabilities of project performance risks were changed by the risk items' change was measured.

Table 2
Risk matrix for Bayesian belief network

Degree of loss \ Probability of occurrence	1	2	3	4	5
5	R2	R2	R3	R3	R3
4	R2	R2	R2	R3	R3
3	R1	R2	R2	R2	R3
2	R1	R1	R2	R2	R2
1	R1	R1	R1	R2	R2

Low risk level: R1, high risk level: R3.

4. An application of project risk management procedure using a Bayesian belief network

4.1. Risk classification and identification

The 26 risk items were selected through interviews with shipbuilding industry experts. The panel of experts consisted of experts working in shipbuilding companies (2 design, 2 R&D, 1 production and production management, 1 finance, 1 sales) and experts working in related industries (2 classification, 2 ship owners, 1 finance). The selected risk categories and 26 risk items are shown in Table 3.

4.2. Risk assessment for a Bayesian belief network

For this study, we visited 11 major Korean shipbuilding companies during April 2007 to conduct a survey, and received responses from 168 experts working in 6 major large shipbuilding companies and 84 experts working in 5 medium-sized shipbuilding companies (producing bulk carriers less than 100,000 DWT (deadweight tonnage), tankers less than 70,000 DWT, containership less than 2000 TEU (twenty-feet equivalent units) and similarly sized other ships).

The average age of the respondents from the large-scale and medium-sized shipbuilding companies was 37- and 35-year-old, with an average work experience of 12 and 9 years, respectively. The demographics of the respondents are shown in Table 4.

The respondents were asked about the probability of occurrence and the degree of loss, measured on a five-point Likert scale (from very low to very high), for each risk item. The risk level was calculated from the survey data using a risk matrix for performing analysis of a Bayesian belief network.

4.3. A Bayesian belief network construction

Two Bayesian belief networks were constructed by structural learning and parameter learning, using GeNIe Ver.2.0 (http://genie.sis.pitt.edu/) and Netica Ver.2.05 (http://www.norsys.com/), respectively, which are types of Bayesian belief network and

Table 3
The 26 major risk items in shipbuilding projects

ID	Risk category	Risk items	Remark
1	Natural	Typhoon, flood, earthquake and other uncontrollable events happen	External
2	Political	Regulations against shipbuilders tighten or are amended	External
3	Legal	Classification's rules change and influence shipbuilders	External
4	Social	Incendiary fire or burglaries occur	External
5	Economic	There is difficulty in supply of raw materials	Internal
6	Economic	Labor costs rise and cause problems	Internal
7	Economic	There is difficulty in meeting labor demands for production	Internal
8	Economic	There are shortages in design manpower	Internal
9	Economic	There is difficulty in supplying production equipment	Internal
10	Economic	Unexpected changes in inflation occur	External
11	Economic	New taxes or big changes in tax rates occur	External
12	Economic	Unexpected changes in exchange rates occur	External
13	Financial	Unexpected changes in interest rates occur	External
14	Financial	Changes in company credit ratings occur	Internal
15	Financial	Refund guarantee, operating costs and other difficulties in capital funding occur	Internal
16	Financial	Unexpected difficulties in cash flow occur	Internal
17	Technical	Changes in design occur	Internal
18	Technical	Introduction of new technologies incur new risks	Internal
19	Technical	Failures in production equipment occur	Internal
20	Technical	Instances arise where the specifications of the shipbuilding contract cannot be met	Internal
21	Managerial	Productivity does not improve	Internal
22	Managerial	Problems in quality management arise	Internal
23	Managerial	Problems arise due to strikes at headquarters	Internal
24	Managerial	Problems arise due to strikes at subcontractors	Internal
25	Managerial	Time schedule is exceeded and does not go according to plan	Internal
26	Managerial	Budget is exceeded and does not go according to plan	Internal

Table 4
Respondent demographics

	Large-scale shipbuilding companies	Medium-sized shipbuilding companies
Age (mean)	37.4	35.4
Under 30 years old	23	29
31–40 years old	95	34
41–50 years old	46	17
51 or above	4	4
Work experience (mean)	12.0	8.8
Under 4 years	24	38
5–9 years	43	19
10–14 years	50	9
15–19 years	16	6
20 or above	35	12
Position		
executives	–	5
General manager	53	20
Manager	96	45
Staff	19	14
Department		
sales	13	7
Production	23	41
Design	100	12
R&D	31	1
Etc.	1	23

decision support software. Two Bayesian belief networks for large-scale and medium-sized shipbuilding companies are shown in Figs. 2 and 3, respectively.

Tables 5 and 6 show the high probability risk items of R3, which is the highest level of risk. The serious risks in large-scale shipbuilding companies were exchange rate, raw materials supply, design manpower, and design manpower, while those in medium-sized shipbuilding companies were labor supply, raw materials supply, design manpower, exchange rate, design change, and capital funding. The major risk items were internal risks other than the exchange rate risk. Exchange rate, raw materials supply, design manpower, and design change were important risk items in both large-scale and medium-sized shipbuilding companies, but medium-sized shipbuilding companies suffered from labor supply and capital funding to a greater extent than did large-scale shipbuilding companies.

In project performance risks (specification discontent, exceeding budget, and exceeding time schedule), exceeding time schedule and specification discontent were larger risks than exceeding budget in large-scale shipbuilding companies, while exceeding budget and schedule were important risk items in medium-sized shipbuilding companies. Detailed results related to project performance risks were as follows.

First, specification discontent was directly related with credit ratings, capital funding, strikes at headquarters and subcontractors, productivity, and quality control in large-scale shipbuilding companies, and strikes at subcontractors in medium-sized shipbuilding companies. Second, exceeding budget was directly related with strikes at headquarters, productivity, and quality control in large-scale shipbuilding companies, and quality control and capital funding in medium-sized shipbuilding companies. Third, exceeding time schedule was directly related with strikes at subcontractors, production equipment supply, quality control, specification discontent, and exceeding budget in large-scale shipbuilding companies, and labor supply, quality control, strikes at subcontractors, and exceeding budget in medium-sized shipbuilding companies.

4.4. Risk control

Entropy reduction (or mutual information) values were calculated for sensitivity analysis of risk items related to project performance. Tables 7 and 8 show the results.

Risk items that affected specification discontent were exceeding time schedule, strikes at subcontractors and headquarters, quality control, productivity, and capital funding in large-scale shipbuilding companies, and strikes at headquarters and subcontractors in medium-sized shipbuilding companies. In both large-scale and medium-sized shipbuilding companies, the risks of strikes at

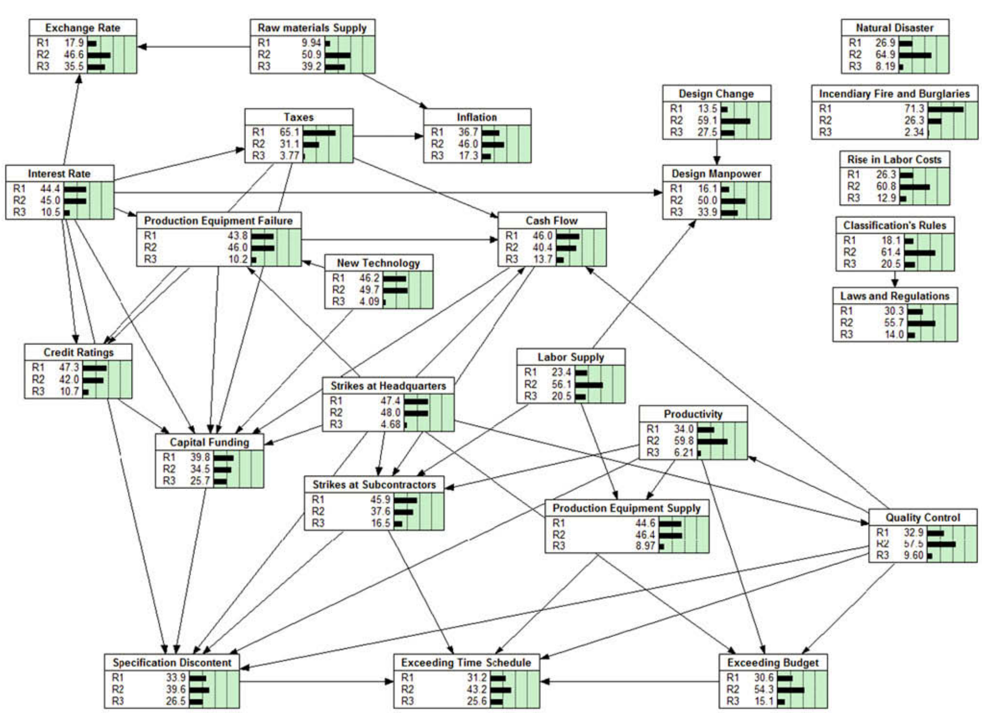

Fig. 2. A Bayesian belief network for large-scale shipbuilding companies.

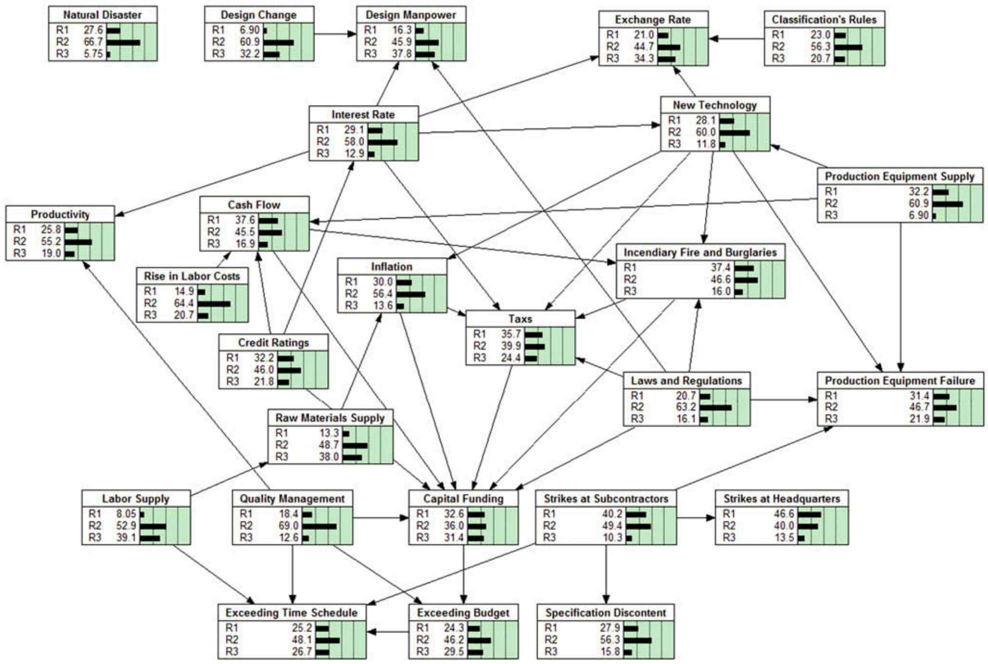

Fig. 3. A Bayesian belief network for medium-sized shipbuilding companies.

Table 5
Major risk items of large-scale shipbuilding companies

Risk item	R3	R2	R1	Remark
Raw materials supply	39.2	50.9	9.94	Internal
Exchange rate	35.5	46.6	17.9	External
Design manpower	33.9	50.0	16.1	Internal
Design change	27.5	59.1	13.5	Internal
Specification discontent	26.5	39.6	33.9	Internal
Capital funding	25.7	34.5	39.8	Internal

Table 6
Major risk items of medium-sized shipbuilding companies

Risk item	R3	R2	R1	Remark
Labor supply	39.1	52.9	8.05	Internal
Raw materials supply	38.0	48.7	13.3	Internal
Design manpower	37.8	45.9	16.3	Internal
Exchange rate	34.3	44.7	21.0	External
Design change	32.2	60.9	6.9	Internal
Capital funding	31.4	36.0	32.6	Internal

headquarters and subcontractors appeared, but the value of entropy reduction of strikes at subcontractors was much larger in the latter. Risk items that affected the exceeding time schedule were exceeding budget, quality control, specification discontent, strikes at subcontractors, productivity, and strikes at headquarters in large-scale shipbuilding companies, and exceeding budget, quality control, strikes at subcontractors, and labor supply in medium-sized shipbuilding companies. In both large-scale and medium-sized shipbuilding companies, the risks of exceeding budget, quality control, and strikes at subcontractors appeared. The risk items that affected the exceeding budget were quality control, productivity, strikes at headquarters, exceeding time schedule, cash flow, and strikes at subcontractors in large-scale shipbuilding companies, and capital funding, quality control, and exceeding time schedule in medium-sized shipbuilding companies.

Since the risk items that affected project performances were all internal risks, risk reduction can be achieved through risk control efforts exerted by shipbuilding companies, and major controllable risks were listed from the sensitivity analysis results.

Table 7
Summary of the sensitivity analysis for large-scale shipbuilding companies

Project performance	Risk item	Entropy reduction
Specification discontent	Exceeding time schedule	0.02309
	Strikes at subcontractors	0.01970
	Strikes at headquarters	0.01507
	Quality control	0.01398
	Productivity	0.01366
	Capital funding	0.01099
Exceeding time schedule	Exceeding budget	0.03769
	Quality control	0.03050
	Specification discontent	0.02309
	Strikes at subcontractors	0.02141
	Productivity	0.01293
	Strikes at headquarters	0.01227
Exceeding budget	Quality control	0.16343
	Productivity	0.09546
	Strikes at headquarters	0.09163
	Exceeding time schedule	0.03769
	Cash flow	0.01863
	Strikes at subcontractors	0.01597

Table 8
Summary of the sensitivity analysis for medium-sized shipbuilding companies

Project performance	Risk item	Entropy reduction
Specification Discontent	Strikes at subcontractors	0.14953
	Strikes at headquarters	0.03587
Exceeding time Schedule	Exceeding budget	0.06010
	Quality control	0.02769
	Strikes at subcontractors	0.01787
	Labor supply	0.01559
Exceeding budget	Capital funding	0.07534
	Quality control	0.07400
	Exceeding time schedule	0.06010

4.5. Risk re-assessment

A Bayesian belief network can calculate the changed conditional probability of other items by the probability change of items, which facilitates the measurement of the risk probability change through the risk control of project risk management. In this study, we measured the reduction effect of strikes at headquarters and subcontractors and quality control utilizing the sensitivity analysis of Chapter 4.4.

Tables 9 and 10 show the probability changes of risk items related to project performance through the risk reduction according to the shipbuilding companies' scale. The R2 and R3 levels exceeding budget risks of large-scale shipbuilding companies were reduced by 22.5% and 8.0%, respectively, through quality control activities, and the R3 level specification discontent and exceeding time schedule risks were reduced by 1.4% and 4.2%, respectively, through subcontractor management activities. If large-scale shipbuilding companies reduced the risk level of quality control and strikes at headquarters and subcontractors, the R3 level risk reductions of specification discontent, exceeding time schedule risk, and exceeding budget risk were 5.8%, 6.4%, and 10.5% respectively.

In medium-sized shipbuilding companies, the R2 and R3 levels exceeding budget risk were reduced by 21.2% and 2.1%, respectively, through quality control activities, and the R3 level specification discontent and exceeding time schedule risk were reduced by 10.4% and 2.4%, respectively through subcontractor management activities. The R3 level specification discontent, exceeding time schedule, and exceeding budget risks were reduced by 10.4%, 2.0%, and 2.1%, respectively, through risk reductions of quality control and strikes at headquarters and subcontractors.

Through the same risk reduction activity, large shipbuilding companies could effectively reduce the exceeding time schedule risk and exceeding budget risk, while medium-sized shipbuilding companies could effectively reduce the specification discontent risk. This variation showed the different effects of the shipbuilding companies' scale.

5. Conclusion and discussion

This study has presented a large engineering project risk management procedure using a Bayesian belief network. The procedure was applied to the Korean shipbuilding industry, with the results demonstrating the difference of risks between large-scale and medium-sized shipbuilding companies, and the relationships among the risk items. For this, we deduced 26 risk items from a literature review and expert interviews, and conducted a survey analysis of 252 experts from 11 major Korean shipbuilding companies in April 2007. This study also identified the major risk items that affected project performance and measured the changes of project performance risks through the control activities of those risk items.

The overall major risks were design change, design manpower, and raw material supply as internal risks, and exchange rate as external risk in both large-scale and medium-sized shipbuilding companies. The world shipbuilding industry has attracted increasing international attention since 2003 due to the rapid growth of international trade with China. Orders of ship-construction have increased by 236% during the last five years (Clarkson Research Service, 2007). This rapid growth of orders may increase the high risks of design manpower, design change, and raw material supply, and also exchange rate because the Korean shipbuilding industry is an export industry. In medium-sized shipbuilding companies, labor supply and capital supply were also the important risks because Korean medium-sized shipbuilding companies are extending their factories as they experience increasing orders. Risk reduction efforts are shared with shipbuilding companies and related industries since the major risks are associated with related industries.

In the analysis of risk items related with project performance, the exceeding time schedule and specification discontent of large-scale shipbuilding companies were more important due to the relative stability of the capital funding ability of large-scale shipbuilding companies. However, exceeding budget and exceeding time schedule were more important in medium-sized

Table 9
Risk re-assessment results of the project performance risks for large-scale shipbuilding companies

	Specification discontent (%)			Exceeding time schedule (%)			Exceeding budget (%)		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
Current situation	33.9	39.6	26.5	31.2	43.2	25.6	30.6	54.3	15.1
R1 = 100% of strikes at headquarters	40.4	34.0	25.5	37.3	38.6	24.1	47.0	42.3	10.7
R1 = 100% of strikes at subcontractors	40.6	34.3	25.1	37.7	40.9	21.4	37.4	49.5	13.1
R1 = 100% of quality management	42.3	31.9	25.8	43.1	32.9	24.0	61.1	31.8	7.1
R1 = 100% of strikes at subcontractors and headquarters	44.4	33.4	22.2	41.7	37.9	20.4	48.0	41.8	10.2
R1 = 100% of strikes at subcontractors and headquarters, and quality management	49.4	29.9	20.7	51.3	29.5	19.2	65.3	30.2	4.5

Table 10
Risk re-assessment results of project performance risks for medium-sized shipbuilding companies

	Specification discontent (%)			Exceeding time schedule (%)			Exceeding budget (%)		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
Current situation	27.9	56.3	15.8	25.2	48.1	26.7	24.3	46.2	29.5
R1 = 100% of strikes at headquarters	37.2	52.0	10.8	27.7	46.8	25.5	24.3	46.2	29.5
R1 = 100% of strikes at subcontractors	48.6	45.9	5.4	31.0	44.7	24.3	24.3	46.2	29.5
R1 = 100% of quality management	27.9	56.3	15.8	36.8	36.0	27.2	47.6	25.0	27.4
R1 = 100% of strikes at subcontractors and headquarters	48.6	45.9	5.4	31.0	44.7	24.3	24.3	46.2	29.5
R1 = 100% of strikes at subcontractors and headquarters, and quality management	48.6	45.9	5.4	41.7	33.6	24.7	47.6	25.0	27.4

shipbuilding companies. Large-scale shipbuilding companies' risk items related with project performance were more various than those of medium-sized shipbuilding companies, and medium-sized shipbuilding companies experienced a higher risk for each risk item than large-scale shipbuilding companies did.

The change of project performance risks was measured by the risk reduction activities of quality management, and strikes at headquarters and subcontractors in both large-scale and medium-sized shipbuilding companies. The present study results demonstrated the different effects of risk reduction activities between large-scale and medium-sized shipbuilding companies. Because large-scale shipbuilding companies produce more complex products such as liquid natural gas (LNG) carriers and ocean plants, it is difficult to reduce the specification discontent risk. Meanwhile, medium-sized shipbuilding companies experienced difficulties due to exceeding time schedule and exceeding budget risk reduction owing to their lack of management capability.

The limitations of this study were the reliance on an expert survey to construct the Bayesian belief network and the consequent requirement for a great effort for data collection.

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